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Redacted Version of Solid Rocket Motor (SRM) Industrial Capability Assessment

J. A. Carlson, Project Leader

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INSTITUTE FOR DEFENSE ANALYSES

IDA Paper P-3462

Redacted Version of Solid Rocket Motor (SRM) Industrial Capability Assessment

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PREFACE

The Institute for Defense Analyses (IDA) has established an Industrial Analyses Center (IAC) to provide the Office of the Secretary of Defense (OSD) with objective and independent analyses that characterize and assess industrial capabilities for acquisition and support of weapon systems. The IAC performs a range of analyses that address industrial issues associated with changing industry structure, competition, and industrial and technology capabilities at the prime and sub-tier contractor levels.

Firms reviewed in this study supply much of the information that IDA uses to perform its analyses. IDA may not be able to independently validate material supplied. As a result, future adjustments to these studies may be required to correct information provided by industry sources. The publication of this IDA document does not indicate endorsement by the Department of Defense, nor do its contents necessarily reflect the official position of that Agency.

This document reports on an analysis done by IDA to address industrial issues associated with Electronic Systems Integration of major weapon systems.

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Introduction

This report summarizes the results of an analysis performed by the Institute for Defense Analyses (IDA) of the current and likely future capability to design and produce solid rocket motors (SRMs) for military applications. The focus is on large SRMs used for strategic and space launch missions. The Director of Industrial Capabilities and Assessments asked IDA to examine this industry for a number of reasons. Orders from DoD have declined precipitously, and all of the current producers are facing significant under-utilization.

This document is a redacted version of a limited distribution document that contains information and projection that may be sensitive to the companies involved in the SRM industry. This version of the report removes all company-sensitive information but retains all other information presented in the original report in order to allow broader distribution of the overall results of the analysis.

A 1993 report of the Science Advisory Group to Strategic Command raised concerns about the SRM industry. Two of the fears prominently expressed in that report have come to pass: SRM sales have declined by about half since then, and it has proven to be very difficult to consolidate this industry in any meaningful way, in part because of environmental cleanup liabilities at SRM producers' facilities. Yet, the assumption is that SRM sales are likely to remain flat or decline and that no strategic SRMs will be produced for an indefinite period after the last Minuteman III is delivered in 2008.

The purpose of this study is to examine not only the likelihood that enough SRM prime capability will remain to design and build a new system but also that the necessary components and materials will be available in the industrial base.

Purpose of Assessment

- Estimate future capability of the industrial base to design and produce solid rocket motors (SRMs) and evaluate factors that will influence this capability.
  - Why
    - 5 current SRM system primes all facing under-utilization
    - Total solid rocket industry sales ~1/2 the level of a few years ago
    - Decade-long gap projected in strategic systems SRM production (Est. 2008-2017)
  - Issues
    - Future availability of industrially capable SRM system primes
      - -- At least 2 SRM primes desired; 3 or more would be better
      - -- Engineering as well as manufacturing capability needed
      - -- Extent to which capability will be maintained by military, civil, and commercial products not clearly defined
    - Uncertain availability of critical sub-tier sources and materials

The facing page clarifies SRM definitions used in this study. These definitions address two dimensions of SRMs: application and size.

One set of definitions specifies what the SRM is used for: strategic military applications, tactical military, or space launch. Each is a distinct segment of the market and has unique requirements, although many overlaps exist in technologies, materials, production processes, and producers. Estimates of future SRM demand were tabulated according to these three segments.

The other characteristic has to do with size. Although technologies and production processes are similar in many cases, significant differences exist in regard to the resources to produce large SRMs and small SRMs. Indeed, most SRM production facilities produce either small or large SRMs—very few produce both. Only Chemical Systems Division and Aerojet have these facilities at the same location.

SRM Definitions Used for This Study

- Strategic SRMs: SRMs used in ICBMs (Minuteman) and SLBMs (Trident D5)
- Space SRMs: SRMs used as stages or as thrust augmentation "strap-ons" in space launch vehicles (SLVs)
- Tactical SRMs: SRMs used in the wide range of tactical applications (2.75-inch rockets, Sidewinder, Hawk, etc.)
- Large SRMs: Diameter $\geq$32 inches
  - Most space launch stages, except for some upper stages
  - Strategic SRMs
  - NMD stages
- Small SRMs: Diameter <32 inches
  - Most tactical missiles are well below this size limit
  - Many other applications: SRM igniters, booster separation motors, auto air bag initiators and other gas generators

The first phase of this project was to describe the current SRM industry and current and near-term capability issues. The development of a detailed taxonomy was basic to understanding the makeup of an SRM and the industry that produces them. IDA identified the key components, materials, and ingredients in each strategic or space SRM, characterized the engineering and production challenges associated with each of these items, and identified the production sources for each item for each SRM.

Particularly important was the identification of sole and single sources for key SRM components, materials, and ingredients. Some of these represent true single source situations, while others simply reflect that purchasers buy from one source, even if other sources are capable of providing the product. The latter case is generally not a serious capability problem because another source usually can be identified and qualified to produce the material.

In the second phase of the project, IDA examined factors that will influence future industrial capabilities: (1) the likely demand for SRMs in the future; (2) federal R&D investments and the technology and business trends that will affect the industry; and (3) long-term capability issues.

The report concludes with IDA's assessment and recommendations.

Assessment Methodology

- Create taxonomy of major SRM components
- Identify “sole sources” of supply for taxonomy items and potential capability problems
  - Single source: Only true source available within region (e.g., USA)
  - Qualified source: Single qualified source for specific application(s)
- Project demand for commercial, civil, and military SRMs and extent of industry supported by this demand
- Examine federal tech base activities, technology, and business trends
- Describe long-term capability and restart issues
- Develop recommendations

Schedule and resource constraints prevented IDA from preparing an in-depth, independent assessment of the SRM industry. As a result, the project team depended heavily on information from other sources, much of which we were not able to verify independently. Detailed data were examined regarding large SRMs, with only broad production revenue and materials information collected for small and tactical SRMs.

In particular, the project team relied on the cooperation of industry personnel as well as DoD and NASA personnel with responsibilities for development, production, or use of SRMs. It would not have been possible to prepare this report without extensive cooperation from numerous individuals at missile manufacturers and SRM producers and suppliers. We also made extensive use of secondary sources, including documents prepared by the Chemical Propulsion Information Agency and IDA's extensive in-house information resources.

The varying degree of cooperation that we received limits a report performed in this manner. Not all SRM primes were willing to identify their principal suppliers, forcing us to rely, in those instances, entirely on secondary sources. Moreover, SRM primes were generally unwilling to share cost information with us; our demand estimates, in particular, are based entirely on an independent IDA estimate of SRM costs.

A final limitation of the study is the significant range of uncertainty with regard to future SRM demands. Our assessment of the future capability of this industry is based on estimates of future demand for strategic, space, and tactical SRMs; significant changes in the levels of SRM purchases could have a large impact on the future capability of SRM producers.

Assessment Scope and Limitations

- Limited IDA effort (~ 8 person-months), focus on large SRMs
- Heavily dependent on outside sources
  - Contractors (SRM primes and suppliers, missile primes)
  - Government program monitors
  - IDA databases, annual reports/10-Ks, and other documentation
  - Chemical Propulsion Information Agency
- Not all SRM primes identified principal suppliers, few supplied costs
- Limited independent verification of data
- Uncertainty about future demand for SRMs

The first section of this report describes the taxonomy of an SRM; suppliers of components, materials, and ingredients listed in the taxonomy; and supply problems that SRM producers currently experience. (A more detailed discussion of this issue is in Appendix A.)

The following section describes the five current SRM primes, their ownership structure, and their future business base likely to sustain SRM capabilities, and discusses current capabilities (market segments, production facilities, labor force).

The next two sections discuss major trends that will affect the future capability of the SRM industry. In the first of these, IDA discusses the estimated future level of SRM demand and the degree to which this demand is likely to help sustain SRM engineering and production capabilities. In the next section, we analyze the extent to which DoD R&D investments are targeted at SRM capability issues and discuss other technological trends that could affect industrial capabilities.

The report concludes with discussions of issues that will affect the long-term capability of the SRM industry, IDA's observations and assessment, recommendations, and selected appendixes.

Organization of this Report

- Taxonomy and supply problems
- SRM primes
- SRM demand projections
- DoD R&D
- Long-term capability and restart issues
- Observations and assessment
- Recommendations
- Appendixes

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SRM Taxonomy and Sources of Supply

A number of factors make the manufacture of SRMs a particularly complex process. First, high reliability and safety is required at every stage of the product's life cycle from manufacturing, storage, and handling of ingredients used to make SRMs through to the manufacture, test, and ultimate operation of the SRM itself. The 1986 Challenger disaster as well as the 1988 destruction of one of two facilities then capable of producing ammonium perchlorate (an ingredient in SRM propellant) both indicated the need for constant vigilance about safety in this business. Together with the requirement for repeatability, this requires very tight process controls throughout the manufacturing process.

Product manufacturing and test also is subject to very strict environmental compliance requirements, including limits on noise, emissions, and disposal of toxic chemicals. The perception that lax environmental monitoring in the past led to serious present-day problems with contamination has increased the concern of producers and environmental authorities.

Supplier requalification represents a particularly difficult problem for SRM producers. Qualifying a new supplier, component, or ingredient can be very costly and time-consuming. The ability to repeat a precise process is critical. Indeed, minor changes in the mixture of chemicals can significantly change the properties of rocket propellants and require further process changes and requalifications. For this reason, SRM producers are singularly reluctant to make changes in suppliers or materials (although it is a problem that SRM buyers and producers deal with frequently and have addressed with considerable success).

Characterization of Product

A number of factors add to the complexity and difficulty of manufacturing SRMs.

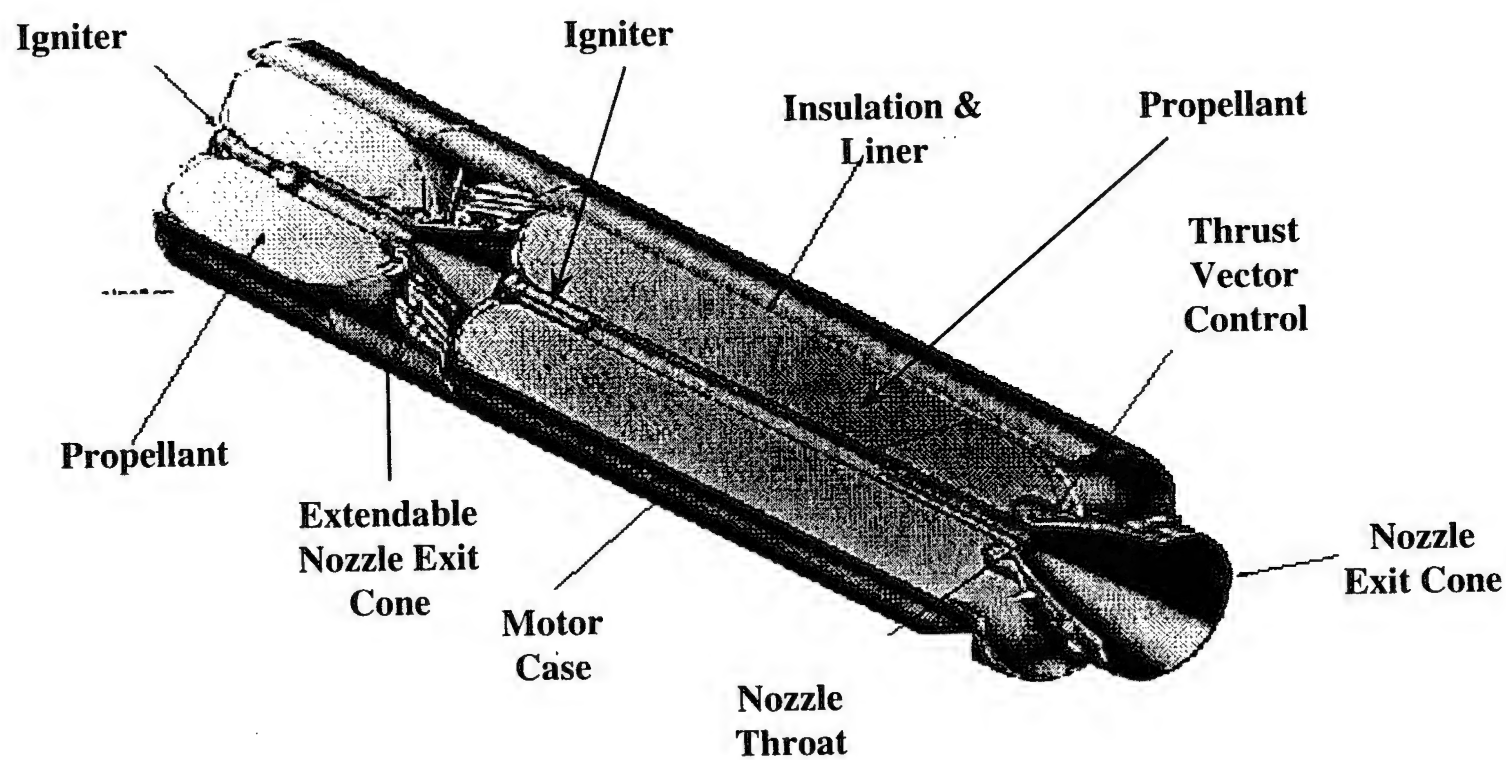
- Very repeatable, homogeneous product
  - Tight process controls
- High reliability and safety required
- No material or process changes desired
  - Supplier requalification can be costly
- Strict environmental compliance requirements for product manufacturing and test

The graphic on the facing page shows a simplified illustration of a typical missile propulsion section containing two SRM stages. Each typical SRM consists of the following components and ingredients: a case, insulation and/or liner, propellant, an ignitor, and the nozzle assembly, consisting of the throat, thrust vector control, and exit cone.

Understanding the taxonomy and underlying supplier structure is critical for any industrial capabilities analysis. The project team developed a more detailed taxonomy and identified sources of major subassemblies, components, materials, and ingredients by taxonomy area for each strategic and space launch SRM. We used this information to understand critical parts of the manufacturing process and to identify and evaluate potential single-source or other industrial capabilities problems.

IDA's conclusions about supplier issues are summarized on the next few pages and discussed in detail in Appendix A.

SRM Taxonomy
(Illustration includes 2 SRM stages)



Although, as noted on page 15, SRM producers are anxious to maintain a stable supply base, they are, in fact, quite experienced and resilient at dealing with supply issues. Solutions to supplier problems include such actions as advance purchases from a source planning to leave the business; finding and qualifying new production sources; or designing problem materials, components, or ingredients out of the system. In most parts of the SRM, we found few supplier problems: either the SRM primes made the key components themselves or there were multiple sources.

Inclusion of internal insulation on this list of "areas with no significant problem" needs some clarification. Internal insulation is used in a considerable variety of formulations, most or all of which are based on ethylene propylene diene monomer (EPDM) compounded with other rubbers and fillers. Such materials are often listed as problems, even in the recent past, and have forced requalification of new suppliers or materials. Although such requalification problems are often expensive and potentially disruptive in terms of continued production in the short term, a number of suppliers are capable of producing such materials; therefore, IDA sees no long-term materials problem.

Areas With No Significant Problem*

In most SRM taxonomy areas, there is adequate production capability for component and ingredient suppliers.

- **Cases: Multiple sources exist for cases and component materials**
- **Insulation: Multiple sources for internal insulation and major ingredients (some source requalification issues due to customary buying practices)**
- **Case liner: Manufactured by SRM primes**
- **Thrust vector control (TVC): Multiple sources for TVC and key components**
- **Igniters: Manufactured by SRM primes**

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* ***Supplier issues addressed in more detail in Appendix A***

Areas of current concern appear to be confined to a number of key propellant ingredients and some materials used in nozzles. In a few cases, key suppliers are currently abandoning the SRM business, leaving SRM producers with only a single qualified source or, in at least one instance, no qualified sources at all.

It is important to note that even where there is only a single source of a key component or ingredient, this does not necessarily represent a severe production risk. Single sources are often preferred to provide for economies of scale and to reward reliable, long-term suppliers. The SRM producers are accustomed to dealing with single-source supplier issues and periodic requirements to design around a problem material or requalify a new supplier, ingredient, or component. These actions can require costly re-design of components or processes and can take a long time, but it is a challenge that SRM builders are accustomed to meeting.

Again, supplier issues are discussed in more detail in Appendix A.

Areas With Some Concern

- Propellant: Single and sole sources for some key ingredients; key supplier(s) leaving the business
  - Oxidizers (HMX, ammonium perchlorate)
  - Binders (HTPB, CTPB, PBAN)
- Nozzles: Single and sole sources for some throat and exit cone sub-assembly suppliers
  - Carbon-phenolic
  - Rayon

Where capability problems exist, the SRM primes and missile buyers routinely handle such problems and are working to develop solutions.

The chart describes particular components/ingredients for which only one U.S. supplier is currently used. Cases in which the supplier is the only U.S. company who makes the product are indicated as "single" sources.

At the current time, North American Rayon (NAR) has shut down its aerospace grade rayon line due to reduced demand. However, they are soliciting business and would like to re-open the line if sufficient demand at appropriate pricing becomes available. In the meantime, NASA and Thiokol are attempting to qualify a Mexican source.

Suppliers of Interest for Strategic SRM Applications

Taxonomy Area	Product [Company]	Single or Qualified Source?	Foreign Producer?	Other Uses of Product?	Other/ Commercial Uses of Facility
Propellant/fuel and oxidizer	Ammonium Perchlorate [AMPAC]	Single	French, Indian sources	Extremely limited	Yes
	HMX [Holston AAP] [GOCO]	Single	British, Norwegian, and Swedish sources	Widespread DoD use in explosives; small Commercial use	No
	Nitrocellulose [Radford AAP] [GOCO]	Qualified	Greek, French, German, and Indian sources	Yes	No
Propellant/ binder	HTPB (aerospace grade) [ELF Atochem]	Qualified		Other uses of similar products	Yes
	PBAN [American Synthetic Rubber]	Single	Japanese, Indian sources	Used on shuttle & MM – No other uses	Yes
	CTPB [Morton]	Single	French source	No	Yes
Nozzle	Carbon Phenolic [Fiberite Cytec]	Single			
	Rayon (aerospace grade) [NAR]	Single (shut down)	Mexican source attempting to qualify	No	

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SRM Primes

Five principal companies make up the SRM industry. Although all have suffered erosion of their SRM business base in the past few years, all five currently have the capability to design and develop SRMs, fabricate components, assemble and test the final product, and perform sustaining engineering.

Not all of the SRM primes are equally strong in all market segments. One of these companies, Atlantic Research, is very strong in production of SRMs for tactical missiles but has never produced a large SRM and would not be in a position to do so without additional facilities investments. Another SRM prime, Aerojet General, lost its longstanding key position in strategic SRMs

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SRM Industrial Capabilities

- 5 SRM primes

COMPANIES	MARKET SEGMENTS
– Aerojet General (GenCorp)	Strategic missiles, tactical missiles
– Alliant Techsystems	Strategic missiles, large and small space launch, tactical missiles
– Atlantic Research Corp (Sequa Corp.)	Tactical missiles
– Thiokol Propulsion (Cordant Technologies)	Strategic missiles, large and small space launch, tactical missiles
– Chemical Systems Div. (UTC / Pratt & Whitney)	Strategic missiles, small space launch, tactical missiles

- All primes have R&D, design, component fabrication, assembly, test, and sustaining engineering

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Aerojet General

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Alliant Techsystems

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Atlantic Research Corporation (ARC)

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Thiokol Propulsion

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UTC Chemical Systems Division (CSD)

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Because of the lengthy hiatus in production of strategic SRMs that will occur a decade from now, DoD has concerns whether there would be a viable capability if it were to decide to design and build a new strategic SRM at some point in the future. DoD must be concerned with two different types of capabilities that will not necessarily be preserved by the same actions and conditions.

One concern is whether SRM primes and suppliers will maintain strategic SRM production capability. Simply stated, the capability to manufacture strategic SRMs is best maintained during a strategic SRM production gap by production of similar SRMs. For this reason, it was important for the study team to understand future demand for SRMs.

But production capability alone is not sufficient; future strategic SRM builders will also need to design and develop the new system. Production contracts alone will not maintain the necessary engineering workforce and skills. Production of SRMs requires far fewer engineers than an active design project, and the engineering workforce assigned to a project is reduced quickly once it enters production. New missile requirements may call for radically new designs. Ongoing R&D programs and other new product activities are necessary to maintain these engineering skills.

Future Viability of SRM Primes

Two factors will determine overall viability of the primes to meet future strategic SRM requirements.

- Production capability
  - Ongoing production of similar products keeps facilities and skilled workers available
  - Projected SRM demand is a key indicator

- Engineering/design capability
  - Continuing exercise of design and integration skills keeps engineers capable and on the job
  - New product activities and R&D program plans are key indicators

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SRM Demand Projections

Current program planning results in a strategic SRM production gap, starting about 10 years from now and continuing for several years. There are, at present, no plans for a replacement strategic system that would keep this production capability on line. It is important for DoD to understand the extent to which other SRM business requires some or all of the same capabilities (and, therefore, whether other SRM business can help sustain essential capabilities during a strategic SRM production gap).

Space boosters are the best surrogates for strategic SRMs. They are roughly the same size, require the same testing sizes, have similar or identical propellant and materials, rely on the same suppliers, and use the same or similar engineering and production facilities. The few differences predominantly are military-specific requirements (very long shelf life, high-energy propellants in some SLBMs, and radiation/EMP hardening). Continued space booster development and production activities could help sustain strategic capabilities.

Tactical motors represent a potential surrogate, although they are not as close a match as space launch motors. Tactical missiles use similar technologies and many of the same suppliers; storage requirements and the requirements for multiple operating environments may actually be more stringent than strategic SRMs.

Liquid rockets provide some synergy in engineering and materials, such as composite pressure vessels and high temperature materials, but there are very few overlaps.

Sustaining Strategic SRM Design/Production Capabilities With Other Business

- Space boosters are best surrogates for strategic SRMs
  - Similarities: Same suppliers, size, propellant, materials, engineering, production facilities
  - Few differences: High-energy propellants, extreme shelf-life requirements, and operation during nuclear exchange not required
- Tactical motors are possible surrogates
  - Similarities: Many of the same suppliers, similar technologies; storage and operating environment requirements actually more stringent
  - Significant differences: Size of product and facilities required to produce/test; physical and organizational separation of production facilities and engineering staffs
- Liquid rockets provide some synergy in engineering and materials (composite pressure vessels, high-temperature materials)

Initially, there was some concern that a trend toward liquid propulsion for space launch vehicles might significantly reduce the demand for solid propulsion. Such a trend could have a significant impact on future strategic SRM capabilities by reducing the synergies between strategic/tactical and space propulsion.

IDA concluded that the trend toward liquid propulsion for military launch vehicles and future reusable launch vehicles will not significantly reduce the need for SRMs during the period of interest (2008-2017).

Because of unique military requirements (storage, launch requirements), virtually all military missiles will continue to require SRMs. This by itself represents a considerable amount of demand; although production of strategic missiles will stop for a prolonged time, overall military requirements will represent a considerable quantity of missiles and SRMs.

Even in space launch, the segment in which the most evidence of a trend toward liquid propulsion lies, the demand for SRMs is expected to remain high. SRMs have many advantages, not the least of which are configuration flexibility and, in many applications, cost.

Characteristics of solid and liquid propulsion are discussed in more detail in Appendix B.

Indications of Continued SRM Use

- Unique military requirements strongly favor use of solid propellants in military rockets and missiles (tactical as well as strategic)
  - Long-term storage in a launch-ready state
  - Minimal maintenance and accessibility required

- Factors favoring continuing usage in space launch applications
  - Flexibility to match payload weights
  - Rapid development/procurement
  - Low non-recurring development costs (compared to liquid stages)

Despite an apparent trend toward liquid propulsion for space launch, both military and civilian markets will continue to require SRMs.

Increased flexibility is one of the primary advantages SRMs have over liquid propulsion for space launch. This is an extremely important factor. With SRMs, space launch vehicle operators and customers can provide combinations of solid strap-on boosters to meet a wide range of lift requirements.

The mix of requirements for space launch capabilities (payload size, satellite orbital altitude, etc.) vary constantly as new satellite markets emerge. High-altitude communications payload sizes are steadily increasing, and the number of small, low-altitude satellites is also increasing. The price-competitive launch range for any given booster is very narrow. Particular liquid vehicle designs match up efficiently with only a narrow range of all potential payloads.

Whereas the only alternatives for handling varying payload requirements in an all-liquid configuration would be to design an all-new booster or to accept the cost or safety penalties of using non-optimal launch capabilities, SRMs provide a relatively easy "mix and match" capability that greatly expands operational flexibility.

SRM Launch Flexibility

SRMs provide flexibility to competitively handle a wide variety of payloads.

- **Price-competitive space-launch ranges are narrow**
  - Space payload lift demands are continually shifting
  - Launch vehicles are price competitive only if closely matched to required payload needs
  - All-liquid launch vehicle designs are matched to only a narrow range of payloads
- **Combinations of SRMs provide greater launch flexibility**
  - Multiple combinations of SRM strap-ons allow a range of lift capabilities
  - Small space-launch vehicles universally use various combinations of SRMs
  - SRMs of different sizes from different manufacturers are often combined in a single vehicle

Because future industrial capabilities for strategic SRMs are so closely linked to the future demand for other types of SRMs, the IDA project team went to considerable effort to develop a demand estimate. The estimates presented in the following slides are the result of careful evaluation and are based on the best information available. We used federal agency program and budget estimates, commercially available forecasts, and, where available, information from SRM and missile producers. These estimates do not include the Navy follow-on SLBM (D-5A), which may begin production near the end of the period.

All of our demand estimates start with 1998 and attempt to forecast potential demand over the next two decades. Key milestones, such as the beginning and ending point of major SRM programs, are shown along the bottom axis of each demand chart. All dollar values are in constant 1998 dollars; no attempt is made to forecast inflation rates.

However, although these estimates are probably as detailed and accurate as any other available SRM demand information, they represent only IDA's estimates and do not represent specific company cost or revenue inputs.

It is particularly important to note that, although these estimates are expressed in dollars, they make no attempt to forecast SRM revenues; they deal only with estimated production demand, are merely an attempt to account for all expected sales in the sector, and do not include R&D funds.

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Production Demand Estimates

- IDA estimates, not based on company cost or revenue inputs

- Based on estimated end-item demand, not anticipated revenues
  - Production demand only
  - R&D funds are not included

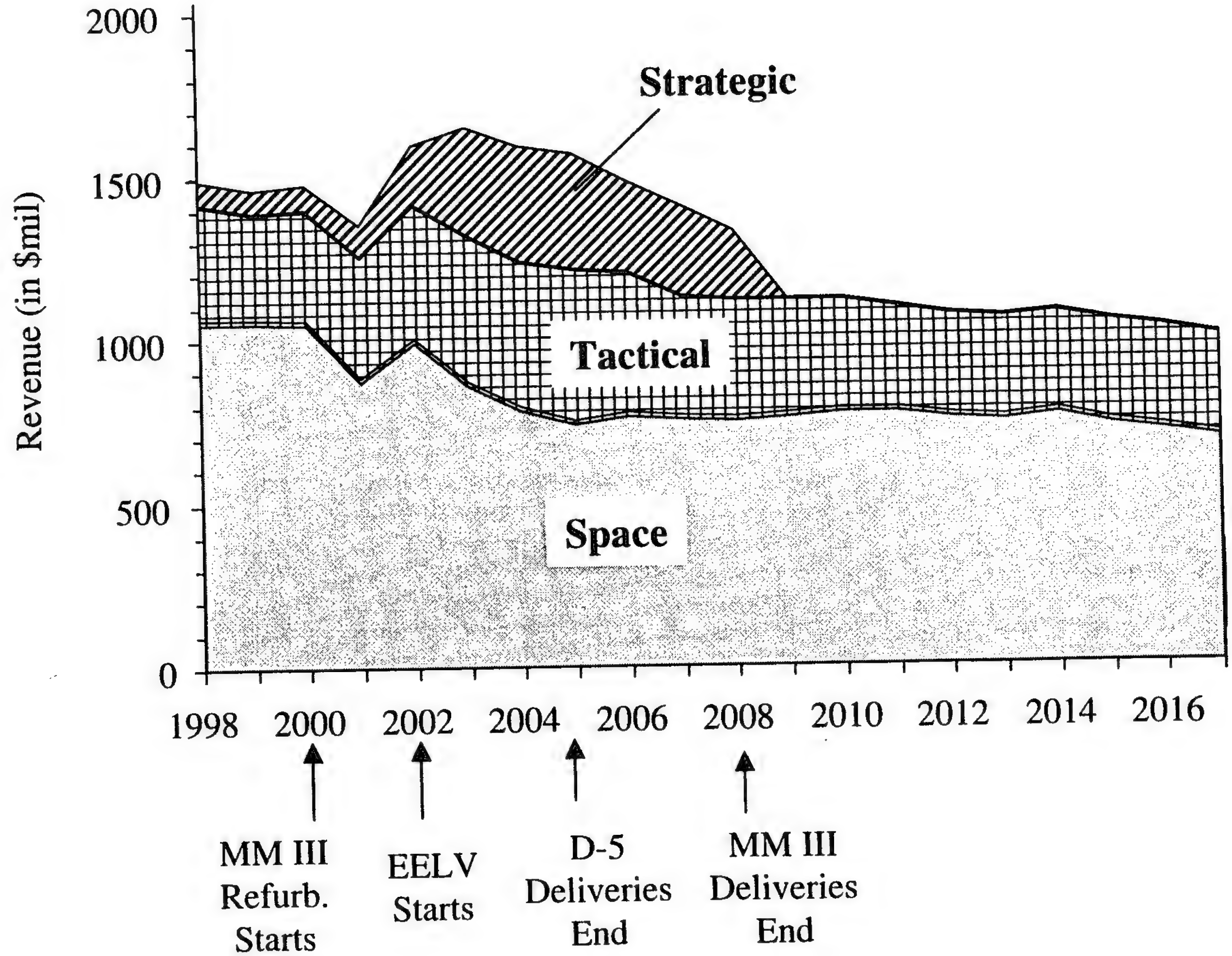
- Sources of information and assumptions for demand modeling
  - Strategic missile projections from Government program sources
  - Space launch forecasts principally from Forecast International (additions made for EELV SRMs, Space Shuttle, and continued Delta II)
  - NMD as per long-range planning (100 interceptors)
  - Tactical delivery numbers from Teal Group, adjusted by available company data, and extrapolated beyond 2006 based on averages of previous production
  - Pricing estimates from IDA and Government sources

This chart shows a summary of estimated SRM production, broken into the three major categories of end-item production: space launch, tactical, and strategic. The chart shows our estimate that space SRM production will decline only slightly over the 20-year period covered by our estimate, tactical SRM production will also decline slightly, and strategic SRM production will come to an end in 2008, with completion of the two ongoing strategic missile programs (Trident D-5 and Minuteman III propulsion replacement). Again, the Navy follow-on SLBM demand is not included.

The relative proportion of production between the three categories shows the critical sustaining role played by production for space. Approximately one-half of this space propulsion revenue comes from the Space Shuttle SRMs procured by NASA.

This "high estimate" chart assumes that NASA budget constraints in the Space Station era, along with the potential for eventual replacement of the Shuttle by a Reusable Launch Vehicle (RLV), will cause NASA to remain with its current shuttle SRM configuration throughout the period we examined. The chart also assumes that RLV technology development will proceed at a pace that does not result in a cost-effective, manned replacement for the Shuttle until the end of the period we examined.

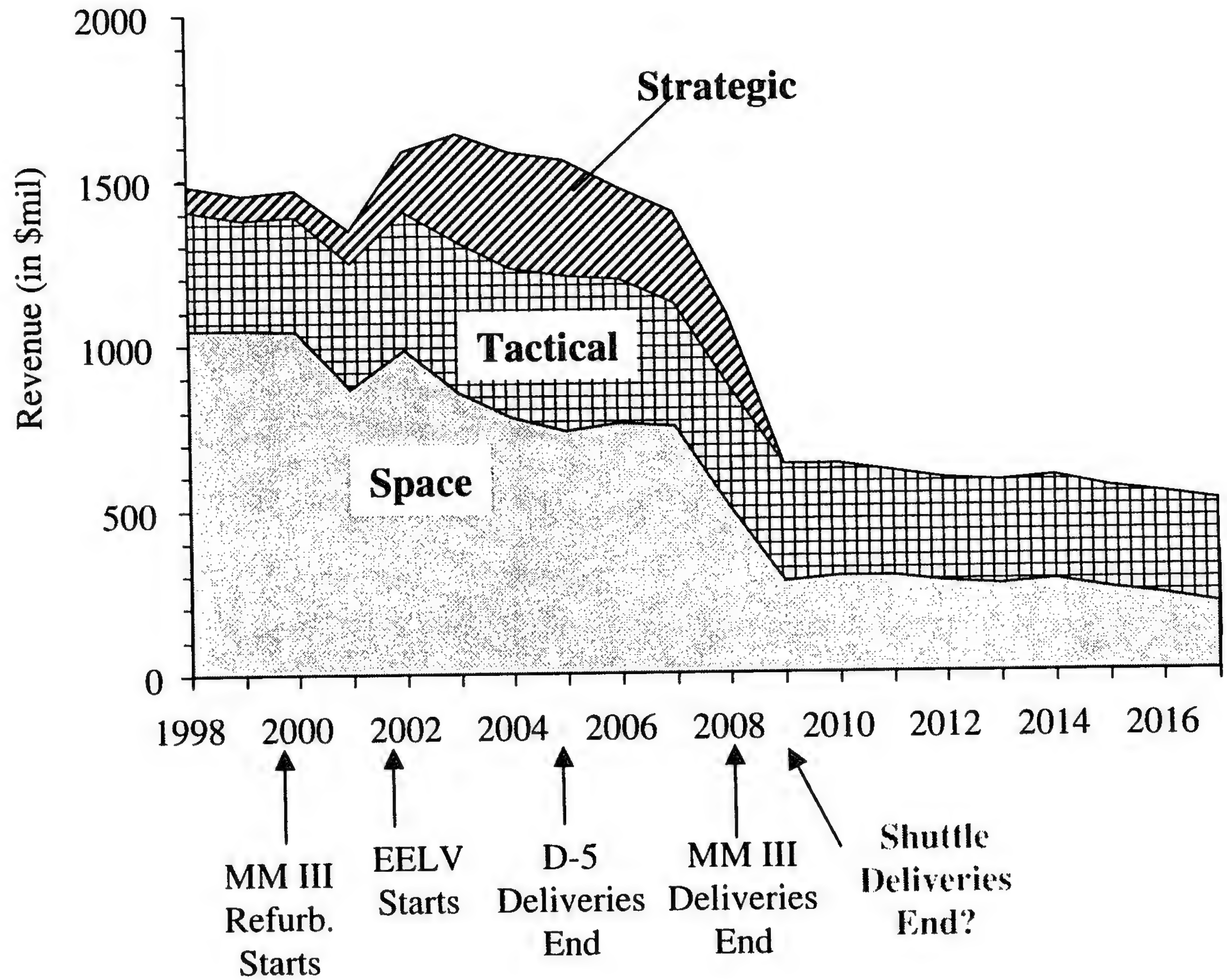
Overall SRM Production Revenue
(High Estimate)



Because IDA's demand estimate was assembled as a "bottom up" calculation of a number of different programs, any of a variety of changes in future demand could influence the accuracy of our estimates. Compared to the previous slide, the accompanying slide shows the impact of one potential change on SRM demand: the cancellation of Space Shuttle SRM orders in 2008. Given that a liquid replacement program for the Shuttle is not yet in the budget, 2008 is the earliest year that transition could be expected, even if development is undertaken. (As discussed elsewhere, the cancellation of the Shuttle would also have a major negative impact on SRM suppliers and supplier capabilities.)

Although no other single event would have an impact of that magnitude, other changes in IDA's demand assumptions would change the revenue estimates shown here—either positively or negatively.

Overall SRM Production Revenue
(Low Estimate)



As noted on the preceding page, termination of Space Shuttle SRM demand would have a major impact on the overall SRM market and an even more serious impact on Thiokol Propulsion. While plans to replace the Shuttle will remain uncertain for years to come, Thiokol's RSRM business could evaporate for any of a variety of reasons, including a decision to abandon the Space Station, another disaster like the Challenger, or a decision to replace solid strap-on boosters with the Liquid Fly-Back Booster.

The impact of continuing Space Shuttle purchases extends far beyond Thiokol Propulsion. The continuing existence of such a large and stable program provides a major source of business for sub-tier suppliers.

The Shuttle program also helps keep the production base current by funding many requalifications that can later be used by DoD. If it were not for the Shuttle, many of these problems would remain unresolved for future system designers.

Impact of Shuttle SRMs

- The majority of Thiokol Propulsion's business would be affected by elimination of Space Shuttle SRM demand
  - Could come about due to crash or cancellation of Space Station
  - Shuttle SRM could also be replaced by Liquid Fly-Back Boosters, though this program is not in NASA out-year budget and couldn't affect SRM demand for a number of years
- Shuttle RSRM provides a large share of workload for subcontractors and suppliers
  - 50% of AP production, for example, is for shuttle
  - Impacts prices charged by suppliers
- Shuttle program also funds many material and component requalifications later used by DoD

IDA made an effort to estimate the long-term minimum level of revenue that might be necessary to keep an SRM builder in the business. However, this proved to be far more difficult than simply calculating workforce size and facilities needed to produce SRMs and estimating the costs of maintaining such a level. Each company is very different in terms of size, backlog, overhead structure, and ownership. A level of sales that would be more than adequate to sustain one producer might be completely insufficient for a producer with a larger burden of facilities and equipment, more debt, or a larger workforce.

While some costs (e.g., engineering and production workforce) can be reduced to compensate for reduced backlog, other costs (e.g., facilities and equipment) are more fixed and are difficult to reduce. Companies may find that they cannot make equivalent cost reductions to match reductions in demand, with the result that they could simply become uneconomical producers.

Moreover, a company's willingness to "ride out tough times" will depend, in part, on how important it is for the company to stay in that business and its perception of the market. Companies may actually continue to operate below their long-term minimum level for a period of time in anticipation of upcoming business. In general, companies were not willing to share this kind of business strategy information with us. The most common answer IDA received when we asked SRM primes about the minimum sales level was "We're about at rock bottom right now." While this seems to be an excessively restrictive answer, we did conclude that there undoubtedly is a bottom figure which SRM producers may be approaching. Page 61 shows the range of "minimum revenue" estimates we made;

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Minimum Sustaining Revenue Estimate Uncertainties

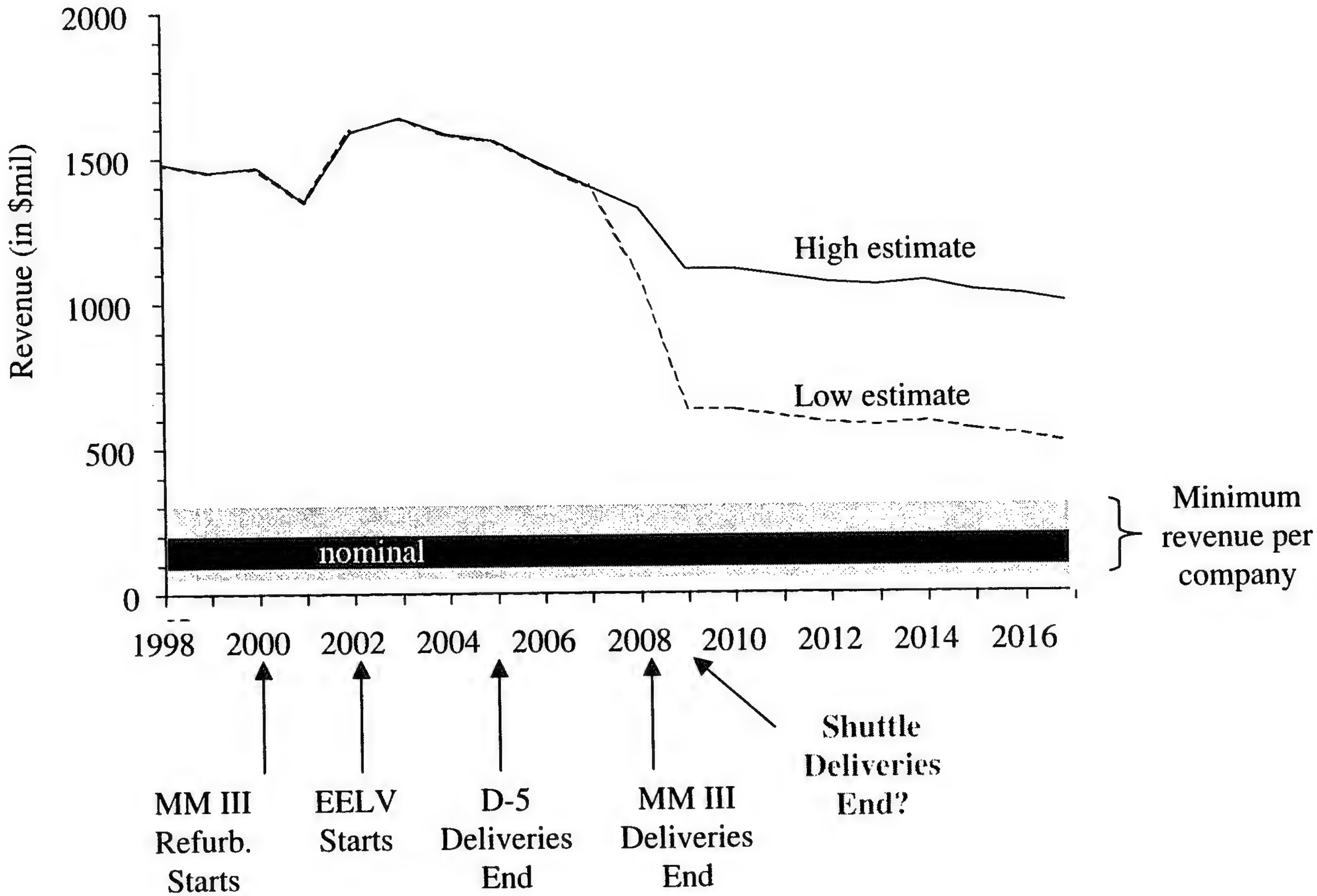
- Company data are dissimilar or unavailable
- Overhead burdens from unused facilities, equipment, and land vary among companies
- Corporate plans and strategies are closely held
- Dynamics of company reductions due to reduced demand are difficult even for company to predict

Perceptions of future business will affect SRM producers' willingness to stay in the business.

This slide shows the same two "high" and "low" estimates of total SRM revenues as presented on a pair of earlier slides and compares these revenue estimates to a rough estimate of the minimum revenue needed to keep an SRM producer in business.

Although the "minimum revenue per company" is an extremely rough estimate, it nevertheless can be used to draw very rough conclusions about the future capability of the SRM industry. From this chart, it can be argued that the low estimate for SRM production should still provide sufficient revenue for two or perhaps three companies. If the high estimate prevails, three or more companies could have sufficient revenue.

Overall SRM Production Revenue



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Estimated SRM Production Revenue

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Although we saw no change in demand or any combination of changes that could wipe out the entire SRM industry, some of the SRM primes are extremely vulnerable to changes in demand on a few programs.

Thiokol has stated that their financial forecasts include long term continuation of the Space Shuttle SRM program as an extremely important component of their business.

Similarly, Alliant's outyear sales potential would be reduced significantly if the SRM program for the new Delta IV EELV were cancelled.

Other uncertainties that could have a significant influence on SRM demand include the status of the National Missile Defense (NMD) program (which could affect both Alliant and CSD)

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Critical Demand Dependencies

Estimated non-strategic demand for each company is highly dependent on a few key programs and assumptions, but no demand fluctuations are likely to wipe out the entire industry.

- Thiokol Propulsion dependent on:
  - Continued need for Space Shuttle SRMs
  - Level of future demand for small space launchers (CASTOR 120)
- Alliant Techsystems dependent on:
  - Level of future demand for Delta II/Delta III/Delta IV with SRMs
  - Size and health of the NMD GBI program
  - Level of future demand for small space launchers (Pegasus and Taurus)
- UTC Chemical Systems Division dependent on:
  - Text deleted
  - Size and health of the NMD GBI program
  - Continued or increased levels of tactical work

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DoD R&D and Technology Development

IDA examined DoD's Technology Base (non-system specific) R&D funding to assess the degree to which DoD investments may contribute to sustaining SRM industrial capabilities. It appears that these investments, for the most part, do not address key industrial capability issues or resolve identified industrial problems.

The Improved High Payoff Rocket Propulsion Technology (IHPRPT) program is the principal funding mechanism for R&D in this area. Funding directed at solid propulsion is modest, at best—$4 million per year directed toward propulsion technology and an additional $4 million annually toward aging and surveillance. (An additional $12 million per year directed toward tactical propulsion technology has some potential applicability to strategic SRM technologies.) In contrast, IHPRPT directs about $40 million per year toward liquid propulsion. In light of the large investments in liquid propulsion for the military EELV program, it would appear more appropriate to redirect the IHPRPT program toward addressing SRM capability and technology issues.

The potential value of IHPRPT in preserving SRM industrial capabilities is also limited because of the scope of the IHPRPT projects. All of the projects fund individual technology efforts; there is no focus on system-level demonstrations.

DoD R&D

- Improved High Payoff Rocket Propulsion Technology (IHPRPT) is the principal SRM R&D program
  - DoD provides most funding; NASA also contributes
  - Estimated 50% of funding remains in laboratory
  - Focuses on individual technology projects, not new system designs
- Majority of IHPRPT funding directed toward liquid propulsion for space launch ($44M of $66M/year average)
- IHPRPT strategic SRM efforts are minimal
  - Propulsion technology ($4M/year) and aging and surveillance ($4M/year)
- Tactical missile effort has some potential applicability
  - Tactical missile production ($9M/year) and materials ($3M/year)

Given commercial investment in liquid propulsion, redirection of IHPRPT to SRM technology would be a first step to retain SRM industrial capabilities.

In addition to specific Federal investments, it is important to understand the general direction in which technology is moving. Technological developments could have a significant impact on future large SRM capabilities to the extent that they cause future defense and non-defense needs to converge or diverge or to the extent that they help resolve or exacerbate individual supplier problems. Several trends are of potential interest.

As noted earlier, there is a general trend in Government/military space launch toward increased reliance on liquid propulsion. However, it is clear that this trend will not eliminate the need for a substantial SRM capability. There is a high probability that the Space Shuttle will continue throughout the study period, and even if it is cancelled, it would simply increase the demand for space launch via other vehicles. The clarification of plans for use of solid strap-on boosters for commercial variants of the new EELV reinforces the potential SRM usage in the future.

Traditionally, DoD's emphasis on performance has differed from the commercial emphasis on cost in a wide range of technology areas. The intensification of competition in the space business has put even more emphasis on cost over performance in this area. DoD's future needs could deviate further from evolving capabilities if they continue to emphasize performance (maximum throw-weight, propellant efficiency, range, etc.).

On the other hand, DoD's interests in use of commercial materials and propellants should continue to increase.

SRM Technology Development

The direction of future space launch technology development will affect industry capability to produce strategic SRMs in the future.

- General trend toward more liquid propulsion for DoD/civil space launch, but will not rule out a major role for SRMs
  - Shuttle SRMs estimated to continue through period
  - Small space launch vehicles using SRMs
  - EELV SRM use planned through 2020

- Interest in use of commercial materials/propellants in defense systems is evident and will probably increase

- Commercial SRM users are demanding lower cost, not higher performance

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Long-Term Capability and Restart Issues

A number of key issues arise when considering the ability of the SRM industry to maintain necessary capabilities and restart strategic production when needed. Necessary capabilities fall into two main areas: design functions and production functions. Maintenance of one of these does not substantially effect the other. For example, all the design expertise in the world will not substitute for the existence of casting pits of the proper diameter or for production workers who are skilled in mixing propellant. Likewise, production of a particular design does not maintain the ability to innovate a new design and to integrate new technologies. The key question for both design and production is: What skills need to be preserved? Another closely related question is: Which necessary skills will be maintained through other types of production that are expected to continue during a gap in strategic production?

Other factors, such as business health and vision, will affect the outcome. Some of the current SRM primes may not be healthy or diversified enough to survive the loss of business during a strategic gap. On the other hand, a strong company may decide to drop its SRM product line because of insufficient profits or a corporate vision to move its business in another direction.

When viewing potential restart of strategic production, it is also necessary to identify the risks involved and the options available to achieve a successful restart. Specific measures need to be analyzed to identify and resolve risks. Potential actions to maintain capabilities and reduce future risk can then be identified.

Key Capability and Restart Issues

- Key design and production capabilities (facilities/ equipment and skills)
  - What skills uniquely need to be preserved?

- Comparability of other types of propulsion
  - To what extent will other production preserve essential capabilities during a strategic SRM production gap?

- Other factors affecting capability
  - Are the current primes strong enough (and motivated enough) to stay in the business?

- Restart risks and options
  - Interim measures to identify and resolve risks
  - Actions to maintain capabilities

As noted earlier, production contracts alone do not maintain engineering and design capabilities needed for follow-on strategic systems. The workforce needs for designing SRMs are very different from what is needed to produce them, and the engineering team starts being reduced immediately once a new system enters production. If a new project is not on the drawing boards to employ these engineers, few companies can profitably carry the engineering workforce for an extended period of time, and even if the company can afford to carry them for a while, the design and integration skills needed for a new system must be exercised regularly if that capability is to be maintained. For example, the Minuteman III refurbishment program does not exercise the engineering capabilities needed to design a new strategic SRM. Thiokol's engineering staff has been maintained through projects such as the design of new Castor IV and Castor 120 space launch SRMs, not from Minuteman III.

Reductions in engineering workforces can have a drastic effect on a company's ability to provide reliable future products. An example of this can be seen in the space launch industry. Both General Dynamics (GD) and McDonnell Douglas (MD) faced drastic reductions in predicted sales of their expendable launch vehicles after the Space Shuttle began operations. GD had laid off most of its engineering workforce but MD had not reached that point when the Challenger disaster occurred in 1986. Tremendous pressure was put on both companies to restart launch-vehicle production. GD experienced low reliability and low demand for many years thereafter, while MD had highly reliable launchers and reaped benefits from strong customer confidence.

Need to Maintain Engineering Teams

- Production alone does not maintain engineering and design capabilities needed for follow-on strategic systems
  - Engineering involvement and team size reduces drastically when moving from design to production (5% of original team remains)

- Even current Minuteman III propulsion replacement program does not sustain Thiokol's engineering crew

- General Dynamics experience contrasted with that of McDonnell Douglas shows long-lasting impact of decisions to reduce engineering workforce
  - Widely varying space-launch reliability upon restart of expendable booster production following Challenger disaster

In the past, SRM and other aerospace companies have made strong efforts to keep engineering teams intact during dry spells in business. Many companies bridged over gaps between development projects by assigning engineering teams to internal or Government R&D projects. Some current civil space-launch systems were developed in this manner, to everyone's benefit—DoD's needs were met because the contractor design teams remained intact, and the companies obtained a new product to sell in commercial markets.

However, a company's willingness to "ride out" a gap depends on its perception that the gap is likely to be temporary and on the availability of worthwhile alternative assignments. The programs that SRM builders pursued as "stopgaps" are completed, and no comparable programs have been initiated. SRM producers are concluding that current conditions do not justify these investments, and engineering workforces are being reduced.

Maintaining Engineering Teams (cont.)

- In the past, companies have bridged program gaps with internal projects or Government R&D
  - Thiokol designed the CASTOR 120 SRM for space launch during last gap using $50M in IRAD
  - Alliant developed the increased size GEM 46 and GEM 60 for commercial purposes
  - But these programs are completed, and economic conditions don't warrant similar investments in new programs

- Subsequently, companies are losing engineering staff
  - Alliant has lost 60% of design and integration staff since the early 90's

The first of the two areas that need to be maintained is the design area. Some of the key engineering and design capabilities necessary to maintain the ability to design a new SRM are listed on this slide. Each of these requires distinctly different skills and must be exercised regularly for engineering staffs to maintain proficiency to successfully undertake a new system design.

Overall project management and coordination skills are just as important and varied as the technical skills used in the different fields of SRM engineering. In the technical realm, the ability to carry through the detailed design of the system and to conduct tradeoff analyses between different design options on the system level is a basic requirement. Skills in designing the diverse subsystem elements are often quite specialized and often call for the use of specialized engineers. One example with regard to SRMs is the development of a propellant to meet specific system constraints and the design of the internal ballistics experienced by that propellant as the engine is fired. Another example is the design of the "avionics" used to control the path of the vehicle through thrust vector control. Development of the manufacturing process and the configuration management system to assure a reliable product are areas quite distinct from those previously mentioned.

Follow-on functions also call for specific skills. Test operations must be designed in concert with the system design team to ensure that the system will function properly. In addition, advanced designs must be undertaken to ensure that products can be developed to benefit from current system's experience and to meet the needs of the future.

Key Capabilities—Design

Some key engineering and design capabilities are necessary to maintain the ability to design a new SRM system.

- Project management and coordination
- System design and analysis
- Propellant development and ballistics design
- Process development and configuration management
- Avionics (controls and actuators)
- Test operations
- Advanced development

From an engineering point of view, strategic SRMs have some special considerations that may call for engineering skills that are unique to strategic design and that SRM designs for other applications do not maintain. Compared to the space SRMs that are their closest surrogate from a production point of view, strategic SRMs have extreme life requirements. These SRMs must sit in submarines or silos for 20 years or more and still perform in a satisfactory manner. This requirement calls for unique design and testing functions as well as designs to provide extensive monitoring functions throughout the system's life.

Cases used in strategic applications are predominantly made from composite material and are designed for high stress loads in order to achieve thrust to weight requirements in a given volume. For this same reason, propellants may be of a unique formulation to achieve high-energy density. Experienced chemists are required to design these propellants, but more attractive opportunities often exist for such chemists, and SRM companies sometimes have difficulty retaining their chemists, especially during slack periods.

Finally, there is a set of requirements unique to military operating environments, such as radiation/EMP hardening and the peculiar operational issues associated with launching from underwater or silos.

Special Considerations for Strategic SRMs

- Extreme shelf life requirements compared to space SRMs
- Composite case design and production for high stress loads during motor operation
  - Tactical cases are usually metal and not as highly loaded
- Specialized propellant design for high-energy density in some applications (SLBMs)
  - Some SRM producers are having difficulty retaining chemists
- Radiation/EMP hardening of components for operation through a nuclear environment
- Peculiarities of underwater- or silo-launched systems
- Continued and extensive SRM monitoring

The facing page shows some of the key capabilities and facilities needed to manufacture large SRMs used for strategic and space applications. While production of any sized SRM requires some equivalent of many of the capabilities shown, the size of large SRMs may require quite different capabilities than other types of production. The difference in manufacturing requirements is underscored by the fact that CSD is the only SRM producer who makes both strategic/space and tactical SRMs in the same facility.

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A primary distinction is the size of facilities required. The manufacturing tooling for production of the large composite cases, the mixing of propellant, the casting/curing of the propellant, the x-ray inspection of SRM sections, the test of final motors, and the handling of large elements (cranes, etc.) must all be sized accordingly. Such large-sized tooling and facilities is a substantial investment for producers, and sufficient capabilities for efficient production of major systems are not likely to be maintained unless predicted demand is sufficient to justify their existence.

Key Capabilities—Production Facilities

- Receiving and inspection of parts and materials
- Storage of parts and materials
- Case preparation/manufacture for large diameters
- Liner and insulator application
- Propellant ingredient storage
- Propellant mixing
- Propellant casting, tooling, and curing for large diameters
- Motor x-ray inspection
- Integration/assembly of subsystems (TVC, nozzles, etc.)
- Production article test
- Test article static firing for large SRMs
- SRM storage/shipping

This slide defines some of the production and test facilities and manufacturing processes that may introduce differences in the production of strategic SRMs compared to other large SRMs. Since propellants are often different between strategic and other uses, both the storage facilities for special ingredients and mixing of specific formulations may not be maintained by other SRM production. Subsystems that are unique to strategic SRMs, such as specific thrust vector control (TVC) and nozzle systems, will require their own peculiar integration and assembly facilities/tooling. Performance requirements of strategic SRMs may likewise require unique facilities for testing.

The manufacturing processes may also have unique characteristics. The cases may need special materials to achieve performance requirements, and these materials will require specialized tooling. Case liners and insulation are closely linked to both the case material, to which they may be bonded, and to the propellant being used. The processes for these unique liners and insulation are likely to be different from those used for other SRM products. Likewise, the processes used for the unique propellant mixes, castings, toolings, and curing are likely to vary from those of other products.

Unique Strategic SRM Production Capabilities

- Production and test facilities
  - Propellant ingredient storage
  - Propellant mixing
  - Integration/assembly of subsystems (TVC, nozzles, etc.)
  - Test article static firing

- Manufacturing processes
  - Case preparation/manufacture with required materials
  - Liner and insulator application
  - Propellant mixing
  - Propellant casting, tooling, and curing

During the 1993 Stratcom study, several SRM primes expressed concern about the risks of not consolidating. They feared that business was insufficient to sustain five healthy SRM producers and that *all* competitors may be weakened unless action was taken to consolidate.

Five years later, SRM orders have declined sharply, but all five SRM primes are still in the business—more or less. However, all five have taken action to adapt. To some extent, all five companies have reduced their emphasis on SRMs, either by buying non-SRM businesses (e.g., Thiokol) or by emphasizing growth in other areas (e.g., ARC and Aerojet). In summary:

- Thiokol bought two non-SRM aerospace companies and created a new parent entity (Cordant Technologies) in which propulsion is only a single business.
- Alliant's SRM business (purchased in 1995 from Hercules Aerospace) is now one of a number of defense businesses owned by this relatively newly formed conglomerate.
- UTC's SRM business (Chemical Systems Division) suffered several key losses and was organizationally combined with liquid propulsion and other space launch-related businesses in the Space Propulsion Operations of Pratt & Whitney.
- ARC's corporate structure remains the same, but the creation of a substantial and growing non-defense business in such things as automobile airbag inflators has substantially blurred their almost exclusive focus on defense.
- Aerojet lost much of its longstanding position in SRMs as both it and its parent (GenCorp) emphasized growth in other areas of Aerojet's product line.

Status of SRM Primes

SRM primes have adopted a number of strategies to adjust to declining SRM business.

- Thiokol diversified into other aerospace businesses and changed its corporate identity to Cordant Technologies
  - SRM reduced from 100% to ~1/3 of company sales
- Alliant has developed a strong position in a range of defense industries
  - Purchase of SRM business from Hercules, Inc., fit with this strategy
  - Text deleted
- UTC reorganized all of its space propulsion businesses (solid and liquid) into a single unit, although they are still geographically separated
- ARC has diversified into non-defense businesses
- Aerojet General has focused on other aerospace/munitions businesses and liquid propulsion
  - Aerojet's parent has announced a new focus on growth businesses

The structural changes made by SRM primes (and their parent companies) in the 1990s do considerably more than insulate the companies against turndowns in SRM business. These changes may have also reduced the stake each company has in the well-being of its SRM businesses—a business that is not as central to the prosperity and growth of any of the five SRM primes as it was even 5 years ago.

It is not apparent that any SRM prime can unilaterally say "we're in this business to stay." Every company now has other businesses and alternative investment opportunities competing for resources. For example, whereas Thiokol, until recently, was basically an SRM company, the head of Thiokol Propulsion now is one of three division heads reporting to the company CEO. Similarly, whereas ARC once was basically "an SRM company," its fastest growing business (airbag inflators) isn't even a defense market.

The ownership changes and structural adjustments that have taken place in this industry also probably increase the likelihood that one or more SRM primes will be sold. Two parent companies (UTC and GenCorp) have already tried (unsuccessfully) to sell their SRM businesses, and two others (Alliant and Sequa) have sold other unprofitable or insufficiently profitable defense subsidiaries.

Longevity of SRM Primes

- Not apparent that any prime can unilaterally assure "we're in this business to stay"
  - No parent company depends on SRM business for its survival and growth
- Ownership changes and declining sales have increased the chances of further restructuring/consolidation
  - Two parent companies (UTC and GenCorp) already tried to sell their SRM businesses
  - Two others (Alliant and Sequa) have sold off other unprofitable defense subsidiaries
- Until now, cleanup liabilities have made it difficult to close or consolidate SRM production facilities

The 1993 Stratcom study cited environmental cleanup liability as a major barrier to "right-sizing" the SRM industry. Indeed, it appears that this was a major factor in GenCorp's inability to sell Aerojet General.

Cleanup liability is still perceived throughout the industry as a barrier to consolidation. Basically, the potential for an open-ended cleanup liability makes it impossible to agree on a fair price. In general, the seller of an SRM producer will want to unload the potential liability while the purchaser is likely to demand some indemnification for potential cleanup costs and penalties associated with actions that took place before the change of ownership.

One significant complication is that standards for what is "acceptable" have changed significantly over the years; substances that once were considered relatively benign are now considered toxic and practices that once were common and accepted now are forbidden. Some argue that DoD should take responsibility for any cleanup liabilities incurred by a company where the original problem was created in the execution of a defense contract and in compliance with rules and practices that prevailed at the time. In essence, DoD's position on environmental cleanup costs is that it will accept liability if DoD is truly responsible, but this is hard to establish. Congress has tended to emphasize recovery of cost from contractors vice Government agencies and has even faulted DoD for allowing too many companies to include cleanup costs among overhead charges. It does not appear likely that DoD will find sufficient grounds to assume the costs and liabilities for a significant portion of past environmental problems in the SRM industry.

Implications of DoD Environmental Liability Practices

- DoD considers cleanup costs for current operations a "cost of doing business" for contractor
  - Items may be chargeable if related to current contract
  - In some cases litigation has established Government liability for contamination resulting from past practices (e.g., Aerojet case)
  - DoD accepts environmental cleanup liability for past operations where DoD is responsible
- Indemnification of contractors may be possible under PL 85-804
  - For losses resulting from unusually hazardous or nuclear risks, if indemnification is in the interest of national defense
  - SECDEF memorandum of decision is required
- Congressional trend is to fund environmental cleanup, but to try to recover cleanup costs from contractors or insurers liable for the damage
- DoD assistance to SRM contractors is unlikely

Company environmental liability viewed as a barrier to sale or complete closure of some facilities.

A number of factors could make it more difficult to resume strategic SRM production after a production gap. Unavailability of manufacturing capabilities, including production facilities, key personnel, or manufacturing processes and process controls, would be a serious problem.

SRM production facilities have been prominently identified as potential environmental hazards, and environmental controls have represented a challenge for SRM producers for many years. Environmental permitting could be a barrier to the construction of new facilities or the reactivation or modification of existing facilities, at either the prime or supplier level.

Measures that will preserve production skills and capabilities will not necessarily sustain SRM engineering capabilities. Even if producers continue to produce a high level of tactical and space launch SRMs, the loss of essential design capabilities would be a substantial barrier to designing a new strategic SRM.

Key suppliers represent a separate, less visible problem. Suppliers are generally subjected to the same market pressures as SRM primes, and many of them have experienced large reductions in their SRM-related business. However, the sources, components, materials, and production processes are similar for all types of SRMs, so continuing production of tactical and space launch SRMs will exercise the lower tiers to some extent.

Restart Risks

A number of factors could make it difficult to resume strategic SRM production after a production gap.

- Loss of critical manufacturing/test capabilities
  - Facilities/tooling or workforce
  - Manufacturing process and process controls
- Environmental permitting for a new, reactivated, or modified facility
- Loss of critical design/engineering skills
  - Workforce, design documentation, or process knowledge
- Unavailability of qualified sources of supply for key components or ingredients
  - Unavailability of the same or similar component
  - Qualification, sourcing, and/or redesign issues

Some requirements for restart would be sustained by continuing SRM production, but others may require special efforts. Although production skills can be kept current through production of other SRMs, production facilities are likely to be kept current by demand for other large SRMs. On the other hand, R&D and prototyping work is necessary to keep engineering skills current.

Sub-tier suppliers are likely to be retained by production of similar SRMs, though undoubtedly some suppliers would need to be requalified before strategic SRM production could be restarted.

Documentation of SRM products and manufacturing/test processes will need to be preserved and updated. Reestablishment of process controls would be a key precursor to any production restart.

Finally, manufacturers would have to reestablish compliance with environmental regulations and develop compliance with new regulations or regulations that were modified during the production gap. Compliance with these regulations, in turn, could require further redesign or requalification of materials, components, ingredients, or sources.

Restart Requirements

- Restart capabilities required
  - Engineering skills kept current through R&D and prototyping
  - Production skills kept current through other SRM production
  - Production facilities available for large SRMs
  - Retention of sub-tier suppliers (production of similar SRMs or requalification of suppliers may be needed)
  - Preservation and updating of SRM product/process documentation and plans

- Environmental regulations
  - Reestablishment of compliance and compliance with changes (may cause need to redesign/requalify materials, ingredients, components, or sources)

- Reestablishment of process controls

The facing slide contains estimates for how long it would take to restart strategic SRM production under varying conditions, depending on how much relevant experience SRM manufacturers gain during the production gap. Obviously, the SRM industry would be able to restart production more easily and quickly if space-launch SRM production and relevant strategic R&D are continued than if the industry's recent experience were confined entirely to tactical missiles.

These estimates are consistent with Air Force experience on analogous programs; with no relevant R&D or production (but with essential documentation in place), the Air Force was able to commence production in 7 years.

Key actions are likely to include the following: build new facilities; engineer learning curve; design, prototype, and test new designs; find and qualify suppliers; and establish manufacturing process controls.

Restart Estimates
(to first prototype)

- If space SRMs are produced and strategic R&D is continued: 3-5 years
- If only tactical missiles are produced, but strategic R&D is continued: 5-7 years
  - Establish process control and requalify suppliers
  - Some new facility construction probably required
- The AF general experience is 7 years, with no relevant R&D or production, but with essential documentation retained and updated
  - Build new facilities
  - Engineer learning curve
  - Design, prototype, and test new designs
  - Find and qualify suppliers
  - Establish manufacturing process controls

Time required to reestablish SRM production capability and build a qualification motor depends on current company status and interim steps taken.

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Observations and Recommendations

Although a number of "sole source" problems in the lower tiers of SRM production have gained national attention (e.g., rayon and ammonium perchlorate), they do not appear to represent critical problems that endanger SRM supply.

For one thing, the industry's successful track record in dealing with single-source, limited-source, and requalification issues provides confidence that it will continue to be successful in identifying and resolving these problems.

In addition, many situations that are described in short-hand terms as "sole sources" really aren't. Formulations of ingredients tend to be application-specific, and SRM builders often establish long-term relationships with a single supplier of a key ingredient or component. Yet few of these situations represent real sole sources; usually, other companies are capable of producing the same product, even if there is a delay and cost in requalifying the new source or modified material.

It is worth noting that some genuine single-source suppliers (e.g., CTPB, a binder used in SRM propellants) are for "old" materials that may only be used in one or a few aging systems. Specifications may be frozen for current systems because of system life cycle or arms control limitations, which dictate the continued reliance on materials that are not widely used elsewhere in the business. While these represent a current problem, they are not as likely to be problems for future systems, where, in all likelihood, the materials would be designed out of the systems.

Observations
—Taxonomy and Sources—

- The industry has much experience dealing with single-source, limited-source, and requalification issues

- SRM builders often establish long-term relationships with one source of a key ingredient
  - Not true "single sources," although requalification can involve time-consuming, difficult, and costly process changes

- A number of single-source suppliers (e.g., CTPB) are for "old" materials
  - Current demand often limited to single or few aging systems
  - High likelihood that problem material will be designed out of future systems

After the last deliveries of Minuteman IIIs take place (in 2008), the demand for large SRMs will primarily come from civil and commercial space launch. As noted, these types of programs provide a close match with the skills, processes, suppliers, and facilities needed to manufacture strategic SRMs, and robust demand for these types of SRMs should go a long way to preserve essential capabilities.

Although our demand model projects future demand for a large number of systems, the long-term health and capability of SRM primes will, in reality, be determined by only a handful of these programs. By far, the fate of the Space Shuttle will have the largest influence on the SRM industry. The ultimate demand for SRM strap-ons for civilian versions of the EELV will also have an important influence on industry demand, and, indeed, may be more important than even the Shuttle in preserving SRM design and engineering capability.

Although tactical SRMs are very different from strategic and space SRMs, there is a good deal of overlap in technologies, processes, and suppliers. However, the potential for synergies is limited because of the way tactical and strategic/space SRM business is distributed. Of the three companies with an appreciable volume of both tactical and strategic/space SRMs, only CSD produces all of its SRMs in a single facility. Both Alliant and Thiokol have concentrated their tactical motor business in separate facilities in the eastern United States (although Thiokol assigns the work to the same division as its large SRM business).

Observations
—Demand—

- Demand at SRM prime level beyond 2008 is principally commercial and civil space launch, which continues at a strong level
  - Space launch provides a good surrogate to maintain strategic SRM capabilities
- A few key programs (e.g., Space Shuttle, EELV strap-ons) will determine whether demand estimates come to pass
- Production of small motors for tactical applications provides additional business and technology activity for SRM primes and suppliers
  - Some degree of overlap appears to exist in propellant usage and materials/ technologies
  - Potential synergy is reduced in several SRM manufacturers due to separate locations and organizations

IDA did not make an in-depth evaluation of current DoD R&D spending on SRMs. However, the review we did make suggests that current tech base funding for SRMs, contained within the IHPRPT program, is extremely modest. The bulk of IHPRPT funding is directed toward liquid propulsion—a spending priority that seems particularly questionable due to Defense dependency on SRMs, the large amount of R&D funding recently spent by DoD on all-liquid EELV programs, and the ongoing commercial interest in liquid propulsion.

Regardless of the spending level, this R&D funding appears *not* to be directed toward solving the potential capability concerns identified in this report. IHPRPT funding is not directed at areas that have been identified as production problems (e.g., designing substitutes for single-source materials) and does not fully exercise all engineering skills needed to design and build a strategic SRM. Additional R&D programs may be needed to exercise the system design and production skills, while individual source issues are already handled by specific programs for that purpose.

Observations
—Tech Base Programs —

- Tech base funding for SRMs is extremely modest
- Current tech base programs do not exercise all engineering skills needed to design and build a strategic SRM
  - IHPRPT only develops technologies, not integrated motors
  - Additional programs may be needed to exercise system design and production skills
- Current tech base funding does not appear to focus on areas that have been identified as single source or supplier problem areas
  - These are approximately dealt with by other programs for this purpose

We have noted that long-term demand should be sufficient to sustain at least two SRM primes to meet DoD needs. The five SRM primes that stimulated concern about over-capacity in the Stratcom study 5 years ago are all still in the business. However, the market position of several has deteriorated a great deal, and it is unlikely that all five will stay in the business over the long term. Although a number of factors (notably environmental regulations) make it difficult to consolidate the industry, discussions are continuing among SRM primes and some consolidation is likely.

The long-term viability of these primes is likely to be influenced by the fact that every one of the corporate parents is now less dependent on SRM business for its prosperity and growth than it was 5 years ago. Either through acquisition or diversification, every company has taken steps to shield the corporate parent from the downturn in SRM sales. Although this diversification means that each company now is more shielded from the economic consequences of reduced SRM sales, this diversification could also affect the willingness of parent companies—who have a greater number of investment options—to "stick it out" during tough times.

Observations
—Long-Term Capability—

- Reduced demand likely will drive industry consolidation over the long term (2010-2020)
  - Past attempts to consolidate SRM primes have failed, but discussions continue and natural "right-sizing" is expected
  - Environmental liabilities and difficulty of transferring skilled workers are primary barriers

- SRM business isn't as central to corporate prosperity and growth for any of the SRM primes as it was even a few years ago
  - Could affect the willingness of parent companies to "stick it out"

Demand will probably be sufficient to sustain at least two SRM primes to meet DoD needs.

Although it will represent a production and management challenge, the design of a new strategic ballistic missile and the restart of strategic SRM production should not be major problems. If DoD needs such systems in the future, it is highly likely that the capability will be adequate to supply them.

The most important factor in maintaining a restart capability will be the continuing production of large SRMs for space launch; the producers of space launch systems will provide a warm base of recent experience with production of very similar systems.

The current prime contractors producing SRMs for only tactical applications provide some additional capability. Given time and money, it would probably be possible for one or more of these firms to scale up to produce large SRMs for strategic or space launch.

There also appears to be enough space and tactical SRM work to maintain most of the critical sub-tier suppliers for SRMs. The overlaps between these areas (in terms of components, materials, and production sources) is strong.

Observations
—Strategic SRM Restart—

- Prime contractors building large SRMs for space applications will provide "warm base"
- Prime contractors building SRMs for tactical applications could scale up, but would probably require more time
- Adequate SRM business (space and tactical) to maintain most of the critical sub-tier suppliers

Given modest lead-time, restart of strategic SRM production is not likely to be a major problem.

Industry's capability to meet DoD's strategic missile requirements are not in serious doubt for the duration of the current strategic missile programs. These programs do not represent significant engineering challenges, and the industry is capable of dealing with periodic vendor requalification and redesign issues as they occur.

Over the longer term, it is expected that the industry will maintain enough capability at the prime contractor and supplier level to produce strategic and other SRMs for military use. Less certain is whether essential design and engineering capabilities will be retained without specific measures by DoD. Ongoing production programs alone will be insufficient to sustain the engineering and design capabilities needed for a follow-on strategic missile SRM. The existing SRM programs that will do most to sustain production capabilities (e.g., Shuttle, EELV, and NMD) will do little to sustain engineering capabilities.

Assessment

- For the predictable future (5 to 7 years) there will be adequate industrial capability
  - Normal vendor management issues continue to exist at sub-tier level, such as vendor requalification and redesign when item no longer available
- Long-term capability is expected, but potential DoD actions for R&D would have high payoff
  - Preservation of long-term capability is heavily dependent on
    - -- Commercial/civil space (notably EELV solids)
    - -- NMD
  - Continuation of Space Shuttle SRM adds important robustness
  - Ongoing and anticipated production alone will not sustain the engineering and design capabilities needed for a follow-on strategic launch system

While there will be a high level of continuing SRM production for tactical and space launch, strategic SRMs are different in many ways. It is important for DoD to document these designs and processes for future reference.

Although current conditions do not justify any immediate action by DoD to preserve SRM capabilities, DoD should carefully monitor the continuing development of this business. While there should be enough SRM capability to meet future DoD needs, this will be affected by a number of uncertainties, including future demand for SRMs and the degree to which SRM producers and their corporate parents remain committed to the SRM business. DoD should monitor how SRM producers react to the emerging business climate.

DoD should reexamine the technology needs for propulsion and determine what programs should be started to address these needs. This includes possible reorientation of its current IHPRPT program to place greater emphasis on SRM technologies; DoD's recent EELV investments and ongoing high-level commercial interest should be enough to sustain technology development in liquid propulsion and SRM propulsion for space. DoD should also consider initiation of separate programs to provide more funds for projects that would improve industrial capabilities, including projects to integrate new technologies, design out problem materials and components, and increase commonality with commercial components and materials.

Recommendations

- Ensure that strategic SRM designs and processes are properly documented and maintained for later reference
- Monitor the continuing development of the SRM business to identify and resolve potential capability issues
- Examine detailed aspects of the technology base and determine what programs may be needed
  - Consider reorienting IHPRPT program funding priorities to emphasize SRM technologies
- Initiate R&D to advance strategic designs and produce prototype hardware demonstrations to maintain design and integration skills during the strategic program gap period
  - Integrate new technologies
  - Design out problem materials and components
  - Increase commonality with commercial components and materials

DoD should consider initiating the development of a next-generation strategic SRM early in the period that would otherwise represent a production gap. Experience has shown that the prospect of an important new program will be enough incentive to keep many suppliers in the business, and there would be a much higher risk if there were no programmatic activities at all.

In 2000-2001, NASA will be making decisions on which of the many possible shuttle upgrades will be undertaken. One of the proposed upgrades is to develop Liquid Fly-Back Boosters (LFBBs) to replace the current SRM. It would be highly beneficial to DoD if the shuttle SRMs are continued because of the significant effect they have on both production volume and component qualifications. If the cost and performance advantages of LFBBs are anything less than overwhelming, DoD should encourage NASA to stay with SRMs.

A number of events are expected to occur in the next 3 years with regard to the SRM industry, and DoD should plan to reassess the industry at that time. The status and production rates for EELV SRMs and other SRMs will be better known then. A particularly strong impact will be NASA's decision on whether to replace the Shuttle SRMs with LFBBs. That decision is planned to be made in 2001, and if LFBB development is started, Shuttle SRMs are likely to be replaced by about 2008, the same year that Minuteman III propulsion replacement production ends. Also by 2001, the firmness of funding for a Navy SLBM follow-on (D5-A) will be clearer and production schedules more accurately known.

Recommendations (continued)

- Consider early (~2008) start of development phase of next-generation strategic SRM

- If NASA tradeoffs between Liquid Fly Back Booster (LFBB) development and continuation of shuttle SRMs are not overwhelmingly supportive either way, DoD should consider encouraging NASA to stay with SRMs due to the large impact they have on DoD's SRM industrial base

- DoD should reassess the status of the large SRM industrial base in 3 years (2001)
  - After the Shuttle SRM vs. LFBB decision is made
  - When firmer schedules are available for the Navy follow-on SLBM program

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Appendix A
Taxonomy and Production Sources

The SRM case is a pressure vessel, made of metal or composite materials. In all likelihood, future strategic SRMs will be made of composite materials.

While the requirements for cases are exacting (ability to withstand heat and pressure), they do not represent critical production problems. We found adequate multiple sources for both metal and composite cases as well as for the materials from which composite cases are made.

SRM Case:

A pressure vessel (metal or composite)

- Metal Case Manufacturers:
  - Steel: Ladish, Petersen
  - Titanium: Titanium Metals (TIMET), Wyman-Gordon, Schlosser
- Composite Case Manufacturers: Alliant, Thiokol, Lincoln Composites, Aerojet
  - Materials:

    Epoxy and Resins: Fiberite Cytec, Hexcel, Thiokol, E.T. Horn

    Graphite Fiber: Hexcel and Toray

    Other fibers in past (Fiberglass and Kevlar)
- Cases will likely be composite for new strategic design

No apparent issues

Insulation is used inside rocket motor cases to protect against the extreme heat involved in SRM combustion. There are no major supplier problems.

However, there are occasional difficulties with EPDM rubber compounded with other rubbers and fillers. Although these materials have many sources and commercial uses (e.g., roofing materials, pond liners, playground safety surfaces), suppliers of these materials for SRM liners typically are qualified uniquely for each application. As a result, buyers must requalify a new supplier any time a supplier changes processes or leaves the business. This can be expensive and time-consuming and can even force the manufacturer to make other process changes, but it is a problem that the SRM industry is accustomed to solving.

Insulation:

Thermally insulating material inside case

- Insulation manufacturers: R.E. Darling, Kirkhill, Alliant, Lincoln Composites, Garlock, Thiokol
- Insulation typically has 2 major ingredients: elastomer and filler
  - Elastomer (e.g., rubber) suppliers:
    EPDM: Kirkhill, R.E. Darling, Burke
    Nitrile Butyl Rubber: Kirkhill
    Polyisopropylene: Garlock
  - Filler (e.g., Aramid Fibers [Kevlar], Silica, Asbestos): multiple sources
- Lincoln Composites can provide insulation along with cases
- Insulation suppliers typically qualify material sources for each application—continuing requalification issues

No major issues, though ongoing requalification issues for EPDM

There are no specific problems associated with production of the SRM case liner. Because liner material is generally a derivative of the propellant mix, any supplier problems in this area would also show up in propellants (e.g., binders).

SRM Case Liner:

Sticky, non-self-burning layer between propellant and case or insulation

- Manufacturers are SRM primes
  - Formulations vary and are unique to SRM primes
- Materials are compatible with propellant and insulation
  - Frequently a derivative of propellant mix

    Exception: Trident II with embedment grain

No apparent problems (any case liner problems would also be problems in propellants).

SRM propellant is a complex chemical mixture of fuel and oxidant, binders, and other additives. Both the chemical mixture and the composition and shape of the propellant are critically important to ensure that it burns in a uniform and controlled manner.

Like case liners, SRM primes mix their own propellant. Undoubtedly more potential supplier problems exist in this area than in any other part of the SRM taxonomy. Potential supply problems include HMX, a mono-propellant available only from a single domestic source (Holston Army Ammunition Plant, a Government-owned facility), and ammonium perchlorate (AP), an oxidizer now available only from a single domestic source.

The acquisition of ammonium perchlorate has been a supply problem intermittently for the past decade. The first threat to secure supply occurred in May 1988, when the AP plant in Henderson, NV, operated by Pacific Engineering and Production Co. of Nevada (PEPCON) was levelled by an explosion. The plant was subsequently rebuilt in Utah and is now owned by Western Electrochemical Co. (WECCO), a subsidiary of American Pacific Corp. (AMPAC). Concerned about over-capacity in this business, AMPAC negotiated an agreement to purchase the AP production capability of the other producer, Kerr-McGee Corp., making AMPAC in effect the sole producer of AP in North America.

Propellant:

Important Characteristics:

—Must burn uniformly and controlled—

—For military, must have very long shelf life (~20-30 yr)—

- SRM primes manufacture propellant
- Materials:
  - Fuel and Oxidizer

    HMX: mono-propellant (Holston AAP)

    Ammonium Perchlorate: oxidizer
    - AMPAC (WECCO): single U.S. source
    - SNPE (France) new (second qualified) source for Ariane 5

    Powdered Aluminum: fuel
    - Alcoa, Alcan, Valimet, Toyal, Eckart

Several binders are also single source problems, including hydroxyl-terminated polybutadiene (HTPB), polybutadiene-acrylic acid-acrylonitrile (PBAN), and carboxyl-terminated polybutadiene (CTPB).

During the research for this report, IDA identified a number of foreign sources that might supplement (or compete with) single or sole sources in the United States (for propellants as well as other parts of the SRM). Other nations are developing strong space launch capabilities, so it stands to reason that they would develop sources for many of the same key components and ingredients.

However, the limited time available for this study prevented IDA from evaluating the capabilities of these sources and determining how much effort it would take to establish them as viable sources to help meet U.S. demand.

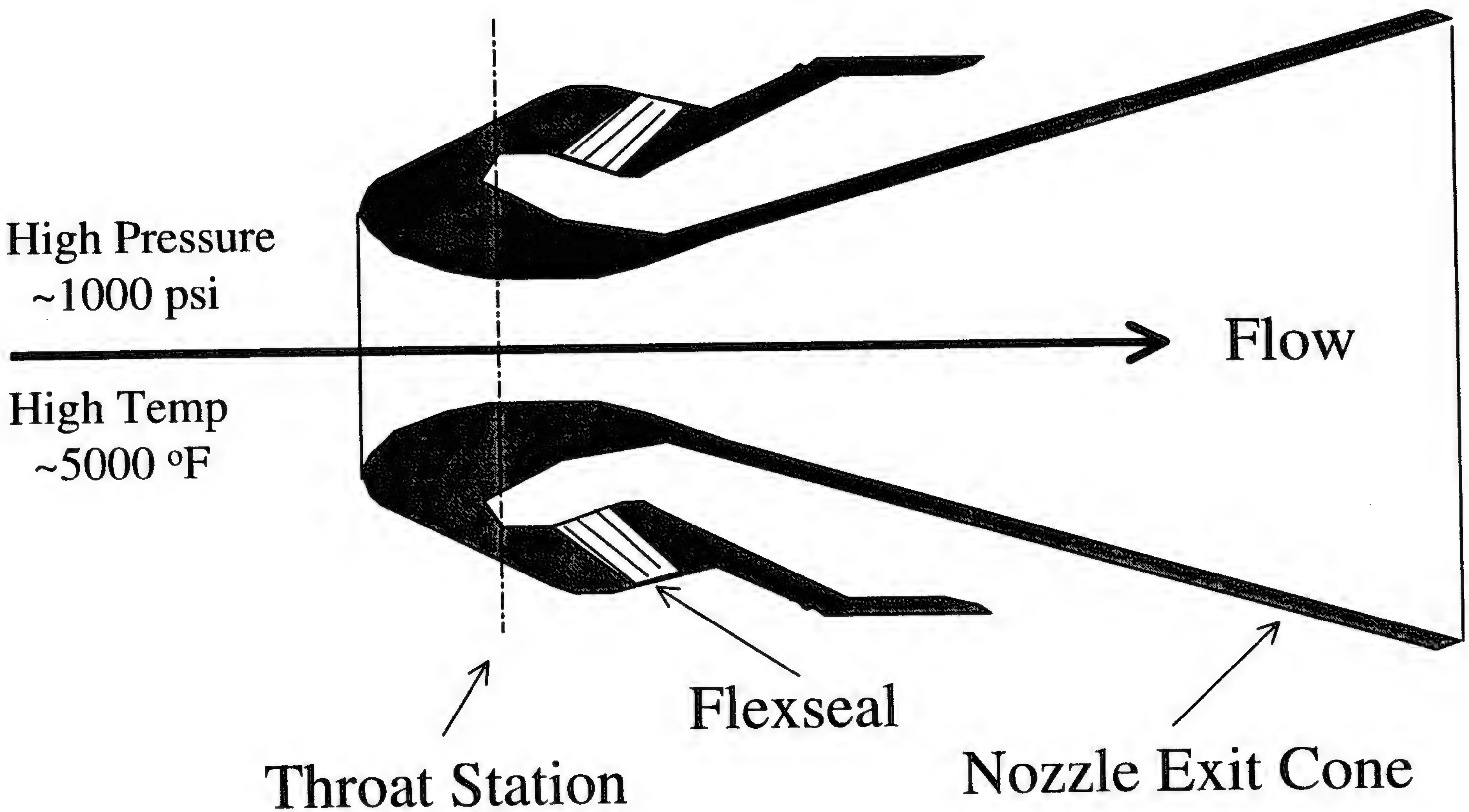
Propellant
(continued)

- Binders:
  - HTPB: Elf Atochem (single U.S. supplier) [France and Japan have sources]
  - CTPB: Morton
  - PBAN: American Synthetic Rubber
- Additives:
  - Can be critical to performance (e.g., control burn rates)
  - Most minor constituents such as plasticizers, curing agents, stabilizers, and ballistic modifiers are acquired by each SRM prime

Many material suppliers are single source, but some foreign sources may mitigate.

This slide shows a stylized cut-away drawing of an SRM nozzle; it is intended to show the location of elements addressed on the next slide. The precise shapes required and the severe environments involved require highly characterized, dependable materials and precision construction techniques. The flex-seal component allows movement of the nozzle to provide thrust vector control (TVC) for steering of the rocket.

Cut-away Illustration of Nozzle with Flexseal



Relatively few manufactured products are subjected to the environmental extremes that an SRM nozzle must withstand. Not only must nozzles operate under extremely high temperature and pressure, but the environment is also extremely corrosive. Although this represents a challenging manufacturing problem, no real industrial capability problems occur at the nozzle or assembly level. In general, there are adequate sources for nozzles and all their major components.

However, a number of potential capability problems do exist at the material level. Carbon-phenolic is available from only a single source—Fiberite-Cytec.

The supply of the rayon precursor material has been an intermittent problem for nearly 2 decades, and there now is no active domestic production source for this item. The former single source (Avtex Fibers of Front Royal, VA) faced intermittent regulatory problems about toxic-chemical disposal and groundwater contamination throughout the 1980s. The facility's operating permit was terminated in 1989 after it was found to be responsible for polychlorinated biphenyl (PCB) contamination of a nearby river, and Avtex declared bankruptcy shortly thereafter. North American Rayon was qualified to replace Avtex's capability, but the Government made a bulk buy of this material after production quantities began to decline and prices started to increase. The plant is now mothballed due to lack of demand, although it probably could be reopened (at some additional cost) if new demand exceeded the stockpiled quantities.

SRM Nozzle:

Must withstand extreme environments:
high temperature & pressure, highly erosive / corrosive

- Nozzle manufacturers: Thiokol, Alliant, Hitco, Kaiser

- Manufacturers of major components:
  - Flex-seal sources: Hitco, Thiokol, Aerojet, Alliant, CSD
  - Nozzle throat subassembly material suppliers:

    3-D carbon/carbon: Thiokol, Alliant, Textron, FMI—[SEP-France]

    4-D carbon/carbon: Thiokol—[SEP-France]

    Carbon-phenolic: Fiberite Cytec (single source)

    Graphite phenolic: Hitco, Kaiser
  - Nozzle exit cone sub-assembly suppliers: Hitco, Reinhold, Thiokol

    Carbon-phenolic: Fiberite Cytec (single source)

    Rayon: North American Rayon (single U.S. source, may be exiting business)

No problem at assembly level,
some issues at material level

Adequate sources seem to exist for thrust vector control (TVC) systems with no serious capability problems.

Thrust Vector Control System:
Mechanisms for altering or directing thrust

- Manufacturers
  - Gas blow down: H.R. Textron
  - Electro-mechanical: Parker Berta, Moog, Allied Signal
- Thrust vector control systems not always provided by SRM prime

No apparent issues

The same SRM primes produce the igniters, and there are no apparent industrial capability issues.

Igniters:

Pyrotechnic or pyrogen sources to ignite the propellant

- Produced by each of the SRM primes

No apparent issues

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Appendix B
Comparisons Between Solid and Liquid Propulsion

Some in the industry have expressed concerns that future SRM design and production capability could be further eroded if non-defense (primarily space launch) uses evolve toward a greater reliance on liquid propulsion. (Strategic missiles must use SRMs because of prolonged storage and the requirement to remain in a launch-ready state.) IDA's analysis suggested that both solid and liquid propulsion have their own strengths and weaknesses and that both will remain in demand for certain types of launch applications. Launch vehicle primes indicate that there are no set rules for selecting between solid and liquid options and that each application must be analyzed before making a choice.

As noted on the facing page, flexibility is one of the key advantages of SRMs. Given the high cost of launch services, the ability to select just the right amount of propulsion to match the specific payload requirements is an important advantage. Without the capability to add or subtract strap-on SRMs relatively easily, payload designers would have to either design new liquid systems or pay for excess capacity to launch many payloads.

Non-recurring costs expended for the development of a new propulsion system are also significantly less for SRMs than for liquid engines. Given the evolving nature of space launch payload demand and the need to develop new stages that may have a relatively low usage rate, cost/benefit tradeoffs often favor the development of solid rather than liquid options.

Attributes of Liquid and Solid Propulsion —for Strategic and Space Applications—

Solid Rocket Motor

- Lower non-recurring development cost
- Rapid development/procurement time
- Shorter (less expensive) qualification
- Long-term, launch-ready storage for strategic SRMs
- Ease of use in varying configurations
  - Different numbers of same strap-on type
  - Different types mixed in one vehicle
- Safety for upper stage in Shuttle (IUS)
- Faster takeoff speed/acceleration
- Much lower part count, fewer failure modes
- Greater range of design options for motor size and thrust

Liquid Rocket Stage

- Lower recurring cost for a specific performance
- Higher ISP (thrust/unit mass flow rate)
- Higher reliability for large stages when compared to multi-segment solids
- Ease of transport of completed stage in unfueled state
- Safety for launch due to ability to shut down engines and abort lift-off
- Ability for long burn-time with multiple starts and stops (important for complicated orbital maneuvers)
- Ability to hot-fire test engine before use
- Softer ride due to slower takeoff speed and ability to throttle engine

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Appendix C
Details of Demand Estimates

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Thiokol: Estimated SRM Production Revenue

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Thiokol: Estimated SRM Production Revenue Low Estimate

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Alliant: Estimated SRM Production Revenue

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CSD: Estimated SRM Production Revenue

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ARC: Estimated SRM Production Revenue

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Aerojet: Estimated SRM Production Revenue

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Although foreign competition is increasing for space launch vehicles and services, the U.S. Government has policies in place that should help SRM builders retain at least their market for U.S. Government payloads.

Use of Foreign Launch Vehicles, Components, and Technologies

Policy is in place to protect U.S. launch industry from unfair foreign competition.

- U.S. Government payloads will be launched on space launch vehicles manufactured in the United States, unless exempted by the President or his designated representative (National Space Transportation Policy, August 1994)
- Implementing DoD Policy on the use of former Soviet Union propulsion in space launch vehicles (William Perry, Secretary of Defense, May 17, 1995)
  - Requires U.S. co-production of foreign-produced propulsion systems, components, or technology
  - Applies to Russian RD-180 liquid rocket engine for EELV
  - Pratt & Whitney required to establish U.S. co-production within 4 years of EELV EMD award

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Appendix D
SRM Project Team Requirements

One of the basic measures of "minimum capability" to design and produce SRMs is the number of personnel necessary to staff an effective project team. IDA discussed these personnel requirements with the Text deleted SRM primes and assembled a consolidated estimate as shown on the facing page.

SRM Minimum Project Team
—($50M/year program)—

The project team estimated the "critical mass" necessary to maintain SRM design and manufacturing capability.

- Engineers dedicated to project
  - 3 Project management
  - 11 Design
  - 2 Manufacturing
- Engineering personnel with part-time support
  - 25 full time equivalents
- Other support (contracts, finance, procurement, scheduling, etc.)
  - 20 full-time equivalents
- Manufacturing workers
  - 30-36: Case
  - 30-36: Propellant (mixing, tool set-up, casting, curing, tool tear-down, non-destructive test)
  - 20-24: Nozzle (for fixed nozzle; 36 for TVC nozzle)
  - 20-24: Final assembly
  - 100-120 (total)

This estimate demonstrates how production programs alone are not sufficient to maintain design capabilities. Although the total number of people assigned to the project increases significantly during the manufacturing phase, the number of engineers actually is reduced.

SRM Project Team—Two Phases
(Example SRM Industry Estimate)

Engineers	Phase: Eng	Phase: Manuf
Chief Engineer	1	1
Project Support	6	2
Design/analysis	5	1
Propellant chemistry	2	1
Process dev/config mgt	6	4
Avionics	3	1
Test	3	2
Total	26	12

Mfg Workers	Phase: Eng	Phase: Manuf
Receiving/inspec	2	5
Case manufacturing		8
Liner/insulation		5
Propellant mixing		10
Casting/tooling/curing		10
X-ray inspection	2	5
Integration/assembly	3	20
Production test	2	5
Test firing	2	5
	20	73

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Appendix E
Glossary

Appendix E
GLOSSARY

AAP	Army Ammunition Plant
AMPAC	American Pacific Corporation
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AP	ammonium perchlorate
ARC	Atlantic Research Corporation
BMDO	Ballistic Missile Defense Organization
CSD	Chemical Systems Division
CTPB	carboxyl-terminated polybutadiene
DLV	Thiokol, Defense and Launch Vehicles Division
DoD	Department of Defense
DSP	Defense Support Program
EELV	Evolved Expendable Launch Vehicle
EMP	electro-magnetic pulse
EPDM	ethylene propylene diene monomer
GD	General Dynamics
GOCO	Government Owned Contractor Operated
HMX	A specific high melting point, high explosive material
HTPB	hydroxyl-terminated polybutadiene
IAC	Industrial Analyses Center
ICBM	intercontinental ballistic missile
IDA	Institute for Defense Analyses
IHPRPT	Improved High-Payoff Rocket Propulsion Technology
LEO	low earth orbit
LFBB	Liquid Fly-Back Booster
MD	McDonnell Douglas
MM	Minuteman

NAR	North American Rayon
NASA	National Aeronautics and Space Administration
NMD	national missile defense
OSD	Office of the Secretary of Defense
PBAN	polybutadiene-acrylic acid-acrylonitrile
PCB	polychlorinated biphenyl
PEPCON	Pacific Engineering and Production Company of Nevada
R&D	research and development
RLV	Reusable Launch Vehicle
SBIR	Small Business Innovative Research
SLBM	submarine-launched ballistic missile
SLV	space launch vehicle
SRM	solid rocket motor
THAAD	theater high-altitude air defense
TVC	thrust vector control
UAV	unmanned aerial vehicle
UTC	United Technologies Corporation
WECCO	Western Electrochemical Company

Appendix F

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13. ABSTRACT *(Maximum 200 words)*

This paper documents an analysis of the current and likely future capability of the solid rocket motor (SRM) industry to meet potential DoD needs for large SRMs for ballistic missiles and other uses. The original report on the SRM analysis had a very limited distribution because it contained information and projections of a company-sensitive nature. The sensitive areas have been deleted from this version of the report, but the document is identical to the original in all other respects. The Industrial Analyses Center (IAC) of the Institute for Defense Analyses (IDA) conducted the work under sponsorship of the Deputy Undersecretary of Defense for Industrial Affairs and Installations [DUSD(IA&I)]. The paper describes the current state of this industry, discusses current supply problems, estimates future demand for SRMs, describes the extent to which SRM producers could be sustained by related, non-military SRM business, estimates the likely future capability of SRM producers, and provides recommendations for DoD consideration. The IAC found that reduced demand is likely to drive industry consolidation over the long term and to be sufficient to sustain at least two SRM primes to meet DoD needs. Production of space-launch SRMs will maintain most manufacturing capabilities, but increased R&D may be needed to maintain engineering capabilities needed for strategic SRMs. Space Shuttle SRM production has a large impact on the industry, and DoD should reevaluate this area following NASA decisions on possible replacement of that SRM.

14. SUBJECT TERMS
solid rocket motor (SRM), strategic missile, ballistic missile, intercontinental ballistic missile (ICBM), submarine-launched ballistic missile (SLBM), space launch vehicle (SLV)

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